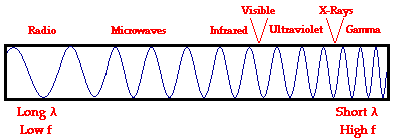
The Electromagnetic and Visible Spectra

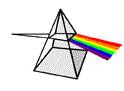
**Electromagnetic waves** are waves that are capable of traveling through a vacuum. Unlike **mechanical waves** that require a medium in order to transport their energy, electromagnetic waves are capable of transporting energy through the vacuum of outer space. Electromagnetic waves are produced by a vibrating electric charge and as such, they consist of both an electric and a magnetic component. The precise nature of such electromagnetic waves is not discussed in The Physics Classroom Tutorial. Nonetheless, there are a variety of statements that can be made about such waves.

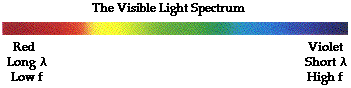
Electromagnetic waves exist with an enormous range of frequencies. This continuous range of frequencies is known as the **electromagnetic spectrum**. The entire range of the spectrum is often broken into specific regions. The subdividing of the entire spectrum into smaller spectra is done mostly on the basis of how each region of electromagnetic waves interacts with matter. The diagram below depicts the electromagnetic spectrum and its various regions. The longer wavelength, lower frequency regions are located on the far left of the spectrum and the shorter wavelength, higher frequency regions are on the far right. Two very narrow regions within the spectrum are the visible light region and the X-ray region. You are undoubtedly familiar with some of the other regions of the electromagnetic spectrum.



**Visible Light Spectrum**

The focus of Lesson 2 will be upon the visible light region - the very narrow band of wavelengths located to the right of the infrared region and to the left of the ultraviolet region. Though electromagnetic waves exist in a vast range of wavelengths, our eyes are sensitive to only a very narrow band. Since this narrow band of wavelengths is the means by which humans see, we refer to it as the **visible light spectrum**. Normally when we use the term "light," we are referring to a type of electromagnetic wave that stimulates the retina of our eyes. In this sense, we are referring to visible light, a small spectrum from the enormous range of frequencies of electromagnetic radiation. This visible light region consists of a spectrum of wavelengths that range from approximately 700 nanometers (abbreviated nm) to approximately 400 nm. Expressed in more familiar units, the range of wavelengths extends from 7 x 10-7 meter to 4 x 10-7meter. This narrow band of visible light is affectionately known as **ROYGBIV**.

Each individual wavelength within the spectrum of visible light wavelengths is representative of a particular color. That is, when light of that particular wavelength strikes the retina of our eye, we perceive that specific color sensation. Isaac Newton showed that [light shining through a prism will be separated into its different wavelengths](http://www.physicsclassroom.com/Class/refrn/u14l4a.cfm) and will thus show the various colors that visible light is comprised of. The separation of visible light into its different colors is known as **dispersion**. Each color is characteristic of a distinct wavelength; and different wavelengths of light waves will bend varying amounts upon passage through a prism. For these reasons, visible light is dispersed upon passage through a prism. Dispersion of visible light produces the colors red (R), orange (O), yellow (Y), green (G), blue (B), and violet (V). It is because of this that visible light is sometimes referred to as ROY G. BIV. (Incidentally, the indigo is not actually observed in the spectrum but is traditionally added to the list so that there is a vowel in Roy's last name.) The red wavelengths of light are the longer wavelengths and the violet wavelengths of light are the shorter wavelengths. Between red and violet, there is a continuous range or spectrum of wavelengths. The visible light spectrum is shown in the diagram below.

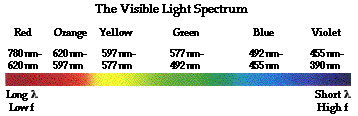


When all the wavelengths of the visible light spectrum strike your eye at the same time, white is perceived. The sensation of white is not the result of a single color of light. Rather, the sensation of white is the result of a mixture of two or more colors of light. Thus, visible light - the mix of ROYGBIV - is sometimes referred to as **white light**. Technically speaking, white is not a color at all - at least not in the sense that there is a light wave with a wavelength that is characteristic of white. Rather, white is the combination of all the colors of the visible light spectrum. If all the wavelengths of the visible light spectrum give the appearance of white, then none of the wavelengths would lead to the appearance of black. Once more, black is not actually a color. Technically speaking, black is merely the absence of the wavelengths of the visible light spectrum. So when you are in a room with no lights and everything around you appears black, it means that there are no wavelengths of visible light striking your eye as you sight at the surroundings.

# Visible Light and the Eye's Response

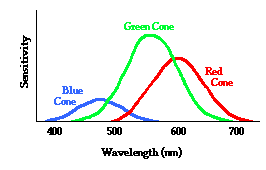
* [The Electromagnetic and Visible Spectra](http://www.physicsclassroom.com/class/light/Lesson-2/The-Electromagnetic-and-Visible-Spectra)
* Visible Light and the Eye's Response
* [Light Absorption, Reflection, and Transmission](http://www.physicsclassroom.com/class/light/Lesson-2/Light-Absorption,-Reflection,-and-Transmission)
* [Color Addition](http://www.physicsclassroom.com/class/light/Lesson-2/Color-Addition)
* [Color Subtraction](http://www.physicsclassroom.com/class/light/Lesson-2/Color-Subtraction)
* [Blue Skies and Red Sunsets](http://www.physicsclassroom.com/class/light/Lesson-2/Blue-Skies-and-Red-Sunsets)

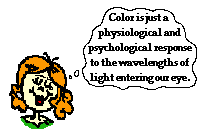
As mentioned in [the first section of Lesson 2](http://www.physicsclassroom.com/Class/light/u12l2a.cfm), our eyes are sensitive to a very narrow band of frequencies within the enormous range of frequencies of the electromagnetic spectrum. This narrow band of frequencies is referred to as the visible light spectrum. Visible light - that which is detectable by the human eye - consists of wavelengths ranging from approximately 780 nanometer (7.80 x 10-7 m) down to 390 nanometer (3.90 x 10-7 m). Specific wavelengths within the spectrum correspond to a specific color based upon how humans typically perceive light of that wavelength. The long wavelength end of the spectrum corresponds to light that is perceived by humans to be red and the short wavelength end of the spectrum corresponds to light that is perceived to be violet. Other colors within the spectrum include orange, yellow, green and blue. The graphic below depicts the approximate range of wavelengths that are associated with the various perceived colors within the spectrum.



**Color Cones**

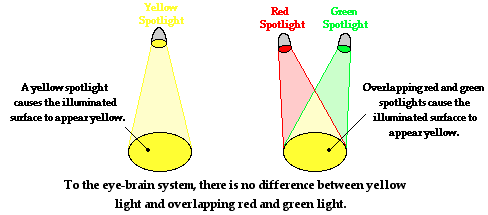
Color can be thought of as a psychological and physiological response to light waves of a specific frequency or set of frequencies impinging upon the eye. An understanding of the human response to color demands that one understand the biology of the eye. Light that enters the eye through the pupil ultimately strikes the inside surface of the eye known as the **retina**. The retina is lined with a variety of light sensing cells known as rods and cones. While the rods on the retina are sensitive to the intensity of light, they cannot distinguish between lights of different wavelengths. On the other hand, the cones are the color-sensing cells of the retina. When light of a given wavelength enters the eye and strikes the cones of the retina, a chemical reaction is activated that results in an electrical impulse being sent along nerves to the brain. It is believed that there are three kinds of cones, each sensitive to its own range of wavelengths within the visible light spectrum. These three kinds of cones are referred to as red cones, green cones, and blue cones because of their respective sensitivity to the wavelengths of light that are associated with red, green and blue. Since the red cone is sensitive to a range of wavelengths, it is not only activated by wavelengths of red light, but also (to a lesser extent) by wavelengths of orange light, yellow light and even green light. In the same manner, the green cone is most sensitive to wavelengths of light associated with the color green. Yet the green cone can also be activated by wavelengths of light associated with the colors yellow and blue. The graphic below is a sensitivity curve that depicts the range of wavelengths and the sensitivity level for the three kinds of cones.

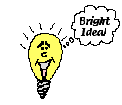


The **cone sensitivity curve** shown above helps us to better understand our response to the light that is incident upon the retina. While the response is activated by the physics of light waves, the response itself is both physiological and psychological. Suppose that white light - i.e., light consisting of the full range of wavelengths within the visible light spectrum - is incident upon the retina. Upon striking the retina, the physiological occurs: photochemical reactions occur within the cones to produce electrical impulses that are sent along nerves to the brain. The cones respond to the incident light by sending a message forward to brain, saying, "Light is hitting me." Upon reaching the brain, the psychological occurs: the brain detects the electrical messages being sent by the cones and interprets the meaning of the messages. The brain responds by saying "it is white." For the case of white light entering the eye and striking the retina, each of the three kinds of cones would be activated into sending the electrical messages along to the brain. And the brain recognizes that the messages are being sent by all three cones and somehow interprets this to mean that white light has entered the eye.

Now suppose that light in the yellow range of wavelengths (approximately 577 nm to 597 nm) enters the eye and strikes the retina. Light with these wavelengths would activate both the green and the red cones of the retina. Upon striking the retina, the physiological occurs: electrical messages are sent by both the red and the green cones to the brain. Once received by the brain, the psychological occurs: the brain recognizes that the light has activated both the red and the green cones and somehow interprets this to mean that the object is yellow. In this sense, the yellow appearance of objects is simply the result of yellow light from the object entering our eye and stimulating the red and the green cones simultaneously.

If the appearance of yellow is perceived of an object when it activates the red and the green cones simultaneously, then what appearance would result if two overlapping red and green spotlights entered our eye? Using the same *three-cone theory*, we could make some predictions of the result. Red light entering our eye would mostly activate the red color cone; and green light entering our eye would mostly activate the green color cone. Each cone would send their usual electrical messages to the brain. If the brain has been psychologically trained to interpret these two signals to mean "yellow", then the brain would perceive the overlapping red and green spotlights to appear as yellow. To the eye-brain system, there is no difference in the physiological and psychological response to yellow light and a mixing of red and green light. The brain has no means of distinguishing between the two physical situations.



In a technical sense, it is really not appropriate to refer to light as being colored. Light is simply a wave with a specific wavelength or a mixture of wavelengths; it has no color in and of itself. An object that is emitting or reflecting light to our eye appears to have a specific color as the result of the eye-brain response to the wavelength. So technically, there is really no such thing as yellow light. Rather, there is light with a wavelength of about 590 nm that appears yellow. And there is also light with a mixture of wavelengths of about 700 nm and 530 nm that together appears yellow. The yellow appearance of these two clearly different light sources can be traced to the physiological and psychological response of the eye-brain system, and not to the light itself. So to be technically appropriate, a person would refer to "yellow light" as "light that creates a yellow appearance." Yet, to maintain a larger collection of friendships, a person would refer to "yellow light" as "yellow light."